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THE INFLUENCE OF AGILITY TRAINING ON PHYSIOLOGICAL AND COGNITIVE PERFORMANCE

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14. ABSTRACT.
Agility training (AT) has recently been instituted in several combat athlete communities in hopes of improving combat performance as well as general fitness. AT has been demonstrated to improve performance in agility tests while traditional linear exercise does not. Further, in animal models, while exercise alone offers some neurological benefits, studies suggest a greater benefit from AT. The purpose of this study was to determine how substituting AT for traditional linear running influences physiological and cognitive performance. Forty-one subjects undergoing military technical training were divided randomly into two groups for 6 weeks of physical training (PT). One group participated in standard military PT of calisthenics and moderate linear running. A second group duplicated the volume of exercise of the first group, but used AT as their primary mode of PT. Prior to and following training, subjects completed a physical and cognitive battery of serum cortisol, VO_2max, vertical jump, reaction time, Illinois Agility Test, body composition, visual vigilance, dichotic listening, and working memory tests. There were significant improvements for the agility group in VO_2max, Illinois Agility Test, visual vigilance, and continuous memory. There was a significant increase in time-to-exhaustion for the traditional group. There were strong trends toward the agility group improving more than the traditional group on VO_2max ($p=0.12$), vertical jump ($p=0.06$), Illinois Agility Test ($p=0.07$), and continuous memory ($p=0.07$.) We conclude that AT is as effective or more effective as linear running in enhancing physical fitness. Further, it is potentially more effective than running in enhancing specific measures of physical and cognitive performance, such as physical agility, memory, and vigilance. Consequently, we posit that AT should be a central component of military PT.

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Agility training, traditional linear training, Illinois Agility Test

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Executive Summary

Purpose:

The primary objective of this study was to determine how substituting physical agility training for traditional military physical training influences physiological performance (physical fitness) and cognitive performance (mental fitness, specifically for this report, working memory and vigilance). Agility training is defined here as exercise that incorporates balance and coordination and enhances one's ability to move and change direction and position of the body quickly and effectively.

Methods:

Forty-one subjects completed a 2.5-hour baseline testing session and an identical post-training testing session six-seven weeks later. The physiological portion of the testing sessions consisted of a DEXA scan for body composition, pre and post physical exercise serum cortisol levels, maximal oxygen uptake, Illinois Agility Test, Makoto reaction time, and vertical jump. The cognitive portion of the testing sessions consisted of dichotic listening, continuous memory, and the visual vigilance test from the NTI Armory. During the six weeks of intervention, subjects were randomly divided into two groups and participated in 45 minutes of physical training three times per week. One group participated in the traditional military physical training consisting of calisthenics (push-ups, sit-ups, jumping jacks, etc.) and moderate distance (1.0 - 3.0 miles) running. The second group duplicated the duration and volume of exercise as the first group, but used agility training as their primary mode of exercise. The agility training consisted of ladder drills, hurdle crossings, dot/footspeed drills, and directional change drills.

Results and Conclusions:

Body weight increased significantly in the traditional group from pre (72.0 kg) to post (73.2 kg) but not in the agility group. The difference in bodyweight change between groups was significant ($p<0.05$.) Both groups increased their percentages of body fat from pre to post testing, although the traditional group gained slightly more fat (1.6 kg) than the agility group (0.9 kg). VO_2max increased by 6.1%, or 2.6 ml/kg/min, ($p<0.05$) in the agility group and by a non-significant 1.7%, or 0.9 ml/kg/min for the traditional group. The agility group significantly improved their Illinois Agility Test times from pre to post testing, while the traditional group did not. Strong trends in favor of the agility group were noted in group by time interaction for the Illinois Agility Test ($p = 0.07$.) and vertical jump ($p = 0.06$). No differences between time or group were noted for cortisol response. The agility group significantly improved continuous memory performance while the traditional group did not and there was a strong trend ($p=0.07$) toward a difference in group by time interaction in favor of the agility group. There were no significant differences noted in group or in time for dichotic listening or visual vigilance.

INTRODUCTION

Objective

The primary objective of this study was to determine how substituting physical agility training for traditional military physical training influences physiological performance (physical fitness) and cognitive performance (mental fitness, specifically for this protocol, memory and vigilance). Traditional military physical training consists of moderate distance linear running, along with calisthenics. Agility training is defined here as exercise that that incorporates balance, concentration, coordination and learning and enhances one's ability to move and change direction and position of the body quickly and effectively while under control.

Background

Functional fitness has recently been championed for its military relevance (Mercer and Strock, 2005) and has gained much traction in the combat athlete community as evidenced by the creation and implementation of the Marine Combat Fitness Test as well as the inclusion of functional training into military PT programs at smaller levels like the 720th Special Tactics Training Squadron (STTS). Functional training is task or occupation specific and for the combat athlete includes a great deal of agility training. Unsurprisingly, specific foot-speed and agility drill training has been demonstrated to improve performance in agility tests (Galpin, 2008.) Traditional linear or "non-skilled" exercise does not appear to benefit agility (Young, 2001.) Anecdotally, agility or motor skill training programs also improve performance in the combat environment.

Agility training may also improve cognitive performance. In animal models, both linear running and agility exercise increase hippocampal neurogenesis (van Praag, Kempermann et al. 1999), resulting in improved spatial navigation and memory. Agility exercise also results in synaptogenesis in the motor cortex (Kleim, Lussnig et al. 1996; Kleim, Barbay et al. 2002) and cerebellum (Black, Isaacs et al. 1990; Anderson, Alcantara et al. 1996; Kleim, Vij et al. 1997; Kleim, Swain et al. 1998) whereas unskilled exercise does not (Black, Isaacs et al. 1990; Kleim, Lussnig et al. 1996; Kleim, Vij et al. 1997; Kleim, Swain et al. 1998.) The ability of agility training to positively affect more regions of the brain may augment its influence on cognitive function. There are currently no published human studies that describe a relationship between agility and cognition. Therefore, this study represents a novel and innovative approach to cognitive enhancement. To support our hypothesis, there are several studies that have examined the relationship between cardiorespiratory fitness and cognition, particularly in the elderly. Angevaren et al. (2008) recently authored a thorough review detailing the effect of enhanced physical fitness on improving cognition in older people without known cognitive impairment. In their review of 11 studies, the authors found evidence that aerobic physical activities that improve cardiorespiratory fitness are beneficial for cognitive function in healthy older adults, with effects observed for motor function, cognitive speed, delayed memory functions, and auditory and visual attention. However, they were unable to posit a causal relationship between cardiorespiratory fitness and cognition, only an associative one. Protocols that have examined the link between physical fitness and cognition in young adults (Themanson et al., 2008) and children (Buck et al., 2008) have reached similar conclusions. Therefore, we believe it is quite possible that a related aspect of physical fitness, such as motor skill training/function, is the primary factor in the associated improved levels of cognition observed in many of these studies.

Agility training may also offer neurological benefit through a modulation of the stress response system. Much attention has been paid to environmental enrichment (EE) and its effect on the hypothalamic-pituitary-adrenal (HPA) axis. The HPA axis responds to stressors by releasing adrenocorticotropic hormone (ACTH) to induce the release of glucocorticoids such as cortisol from the adrenal glands. EE renders the HPA axis response more adaptive and efficient (Larsson et al. 2002; Mohammed et al. 2002) and has been found to reduce the stress response as seen in lowered ACTH levels (Belz et al., 2003.)

METHODS

Participants

Fifty-one United States Air Force School of Aerospace Medical (USAFSAM) Technical Training Students (27 male, 14 female completed), age 18-34, signed institutionally-approved informed consent documents and were enrolled into the study.

Facilities

Data collection was performed at the Air Force Research Laboratory at Brooks City-Base. The six weeks of training was conducted at the Base Fitness Center at Brooks City-Base.

Experimental Design

Each subject completed a 2.5-hour baseline testing session prior to their six weeks of training. The tests included: (a) body composition; (b) venous blood drawn from the subjects' arms for cortisol analysis; (c) physical fitness tests including a 10-12-minute incremental treadmill run for maximal oxygen uptake (VO_2max), a vertical jump test, Illinois Agility Test, and Makoto reaction time test; and (d) a cognitive test battery that included dichotic listening, continuous memory, and visual vigilance tests.

Following the pre-tests, the subjects were randomly placed in one of two groups that participated in a six-week, three days per week physical training program One group participated in the traditional military physical training while the other participated in agility training. The progression of the training mimicked that of a training plan recently adapted by the 720th Special Tactics Training Squadron at Hurlburt Field, FL.

The subjects were asked to keep their physical activity as stable as possible during the 6-week study and to log any additional workouts they did outside of the study. For example, if they exercised more than the usual USAF Physical Training (PT) described here, they should continue to exercise at that level, but not more or less, throughout the study. The traditional group was asked to not participate in any workouts or sports that consisted of directional force change drills, i.e. basketball, soccer, etc.

After the 6-week training period the subjects returned to post-test. The post-testing was identical to the pre-tests they took at their first visit.

Procedures

Body Composition. Subjects' body composition (percent fat and lean muscle mass) was measured using a Dual Energy X-ray Analysis (DEXA) Lunar Prodigy scanner by GE (General Electric). It is a safe low-energy total-body x-ray that was originally developed to assess bone density, and is now the most accurate method to assess body composition (even more accurate than under-water weighing). Subjects laid comfortably on a table while the x-ray arm passed slowly over them.

Venipuncture (Cortisol Levels). Approximately 3 ml (less than a teaspoon) of venous blood was drawn from the subjects' arm by a trained phlebotomist. This occurred twice per testing session, once before the physical testing portion and once when the physical tests were completed. Samples (without indentifying info) were sent to the Wilford Hall Medical Center Laboratory for a measurement of their cortisol levels.

Cardiorespiratory Endurance. Maximal oxygen uptake (VO_2max) and running economy protocols were conducted on a Woodway DESMO treadmill (Woodway USA, Waukesha, WI). Each subject was fitted with a harness and a facemask to collect expired air for the Parvo Medics' TrueOne 2400 metabolic measurement system (Consentius Technologies, Sandy, UT). Subjects wore a Polar heart rate monitor transmitter (Polar Electro, Inc., New York, NY) around the chest to measure heart rate (HR) response throughout the warm-up, test, and recovery phases of the protocols. After a one-minute rest period to verify transmitter communication, subjects performed a two-minute walk at a 2.0 mph. Upon completion of the two-minute walk, treadmill speed increased to 6.0, 6.5, or 7.0 mph, depending on the self-reported fitness level of each subject, at 0% grade. This speed and grade were maintained for three minutes to test for 7.0 mph running economy. Following that stage, the 7.0 mph speed was maintained while the grade increased by 2% increments every minute until it reached a 10% grade, after which it increased by 1% each minute until it reached a 15% grade or until subjects reached volitional fatigue. Once volitional fatigue was reached, the treadmill's speed slowed to a 2.0 mph pace at 0% grade to induce active recovery until the subject's heart rate dropped below 120 bpm.

Whole Body Reaction Time. Eye-hand reaction speeds were measured using The Makoto Interactive Sports Arena™ (Makoto USA, Centennial, CO) in the three tower reactive mode. A 30 second practice was given in the proactive mode prior to the 90 second reactive test, with a one minute rest in-between. The towers were set up in a triangular manner and at each of the three corners there were six foot posts that have 10 embedded lights. During a test, lights illuminate one at a time in random order across all three towers with a corresponding tone that's pitch varied depending on the height of each panel. Each panel sounded and illuminated until struck using a hand-held medicine ball. Each time a target is struck, another turns on at an operator-controlled time interval. For the 30 second practice in a proactive mode targets remained lit until struck or for 3.0 seconds. The average time to hit the targets and the percentage of targets hit was recorded. During the 90 second reactive mode test, the targets stayed active for only a set time, whether they were struck or not (1.20 seconds). The average time to hit the targets and the percentage of targets hit were recorded. The subjects were scored both on how quickly they could hit each panel and on how many panels they were successful in hitting. If the subject did not hit the target in the allotted time then it was recorded as a miss. The results of this test were the percentage of targets hit and the average time to hit each target.

Power. A Vertec (Questec Corp., Northridge, CA) Vertical Measuring Device was used to measure vertical jump height. Standing height of the subject was taken with one arm fully extended upward. Then the subject was asked to jump up to touch the highest possible vane while keeping both feet on the ground before starting the jump. Countermovement was allowed but steps were not. The subject continued jumping, with brief rest periods between jumps, until the peak height stalled for three consecutive jumps. Jump height was the difference between standing height and peak jumping height.

Illinois Agility Test. This test is a measure of one's ability to turn and accelerate in different directions at different angles. The test was conducted outside on the pavement. Subjects ran a course marked by four cones, measuring ten meters in length by five meters wide. The cones were used to mark the start, finish, and two turning points. Another four cones were placed down the center in equal distance apart from each other, 3.3 meters. The subjects were given one demonstration of how to run the course and a trial run prior to doing the actual test. The subject started face down on the pavement behind the start cone with their hands by their shoulders. They were then given the command "ready, set, go" and the stopwatch was started. The subjects were then to complete a weaving run through the course of cones in the shortest possible time. The course normally takes 15 – 20 seconds to complete.

Cognitive Testing. Cognitive testing was conducted on computers using three cognitive performance tests of the NTI Armory Test System (NTI ATS). The NTI ATS is a performance battery generation system that selects performance tests most applicable to particular jobs (O'Donnel, Moise & Schmidt, 2005). This battery consists in total of 22 well validated performance tests. For this study we used the three following performance tests:

Dichotic Listening 2. This test is a measure of the subjects' directed attention. O'Donnel et al. (2005) defines directed attention as the ability to allocate resources to a particular task on demand. The goal of this test is to require the participant to attend to auditory information presented in one ear (the "attending" ear) while at the same time, distracting information is being delivered to the "non-attending" ear. To accomplish this, different digits (no letters) are presented to the two ears simultaneously. A cueing tone is presented to the ear that is to be attended to shortly before the digits are presented. This sequence is carried on rapidly, and the subject responds after every letter pair is presented. Subjects were scored on percent correct answers and latency for correct answers.

Continuous Memory Task. Working memory is measured by this test. O'Donnel et al. (2005) defines working memory as the ability to have a continuous awareness of many elements in the environment or many activities that are to be performed at the same time. This task indexed the operator's ability to encode and store information in working, or "short-term" memory. This memory test consists of a random series of visual presentations of numbers (shown in a fraction), which the operator must encode in a sequential fashion. As each number in the series is presented for encoding, a probe number is presented simultaneously. The operator must compare this probe number to a previously presented item at a pre-specified number of positions (one position in this protocol) back in the series. Once the operator has made the appropriate recall, they must decide if that item is the same as, or different from, the probe number. Thus, the task exercises working memory functions by requiring operators to accurately maintain, update, and access a store of information on a continuous basis. Task difficulty is manipulated by varying the number of digits which comprise each item and the length of the series which must be maintained in memory in order to respond to recall probes. Subjects were scored on percent correct answers.

Visual Vigilance. This test measured sustained attention. O'Donnel et al. (2005) defines sustain attention as the ability to concentrate on a task without letting the mind wander. Although simple attention to an easily discriminated stimulus over a period of time appears to be a relatively simple task, it turns out in practice to be extremely demanding. Over long periods of time, subjects find it hard to maintain performance at initial levels (the "vigilance decrement"). They also report high workload and considerable stress. Decrements over time in vigilance tasks lasting 30 or more minutes have been found as a function of diseases, drugs, and other stressors. For the present purposes, a 30-minute vigilance test is generally impractical. An exceptionally strong procedure developed by Temple et al. (2000) produced the same effect with a 12 minute test. These authors also showed significant increases in workload, stress, and other psychological variables as a function of time-on-task over the 12-minute period. Because of the careful analyses carried out by these latter authors, including showing sensitivity of the 12-minute task to performance enhancement by caffeine, an approximation of their procedure was employed.

Essentially, a masking screen consisting of small white circles is presented to the subject. At the start of the test, the letters "O," "D," and a backward "D" are presented in random order in the center of the screen. These letters are generated by placing the figure of the letter on top of the background circles. When the contrast between the letter and the background circles is low, the letter will appear to blend into the background. The letters are presented very rapidly, and the subject's task is to monitor them to detect the "O." If an "O" is detected, the subject makes a response by pressing a response key. No response is required for either of the other two letters. Subjects were scored by the percentage of correct answers within the 12 minutes.

Six-Week Training Program

Agility Training. Agility Training started each day with a functional warm-up for 10 minutes followed by over/under hurdles to stretch the hip flexors.

During the first two weeks, training consisted primarily of pre-conditioning. Subjects were instructed on, and then practiced, how to properly change direction and move laterally. They performed cone drills at a 135 degree angles; box cone drills (shuffle to one cone, carioca to the next, back pedal, and finish with shuffling to the last cone); one foot at a time over the mini hurdles; and one-foot dot drills. They practiced the following ladder drills: fast feet, icky shuffle, scissor, high knees, and stack-n-out ladder drills and they carried a slosh tube (8’ PVC pipe partially filled with one to three liters of water) through a set of cones.

The third and fourth weeks focused on acceleration, deceleration, and more dramatic changes of direction. The third week’s drills consisted of cone drills focusing on their 90 degree cut techniques; the ladder drills included fast feet, scissors (inside and outside of the boxes), stack-n-out, and fast feet to the side while catching a reaction ball; with the mini hurdles they worked on one foot at a time and then using two feet at a time changing 90 degrees directions within the jump; and more complex dot drills. The fourth week continued to work on cutting 90 degree angles with the cones; mirror drills where one subject had to mirror another inside each own boxes; shuttle runs with mini hurdles; and an obstacle course combing all drills they had

practiced, and more advanced ladder drills. The ladder drills consisted of fast feet backwards, scissors out of the boxes, and an in/in/out/out drill.
Weeks five and six focused on explosive change of direction. During this week we put everything the subjects had learned together and demonstrated/practiced their ability to accelerate, decelerate, and change direction in a controlled, efficient and explosive manner, even when the change was not anticipated. Week five consisted of change in direction cone drills with unexpected 90 degree cuts during shuttle runs; change in direction drills in which the subjects reacted to the blowing of a whistle and hand movements directing which way to turn; box drills (sprint diagonal then backpedal and sprint forward then shuffle) and ladder drills. Ladder drills consisted of hop scotch, lateral high knees, lateral scissors with double feet backwards jump in between, and 90 degree turns while advancing forward in the ladder. Subjects also completed a more advanced obstacle course consisting of cone drill cuts, two ladder drills, hurdles, shuttle runs, and box drills. Week six worked on combining all previous work and perfecting each drill. We also added a catching task to the cone drills and to the ladder drills so that subjects were forced to look away from their feet and concentrate on catching while still executing proper changes of direction.

The agility group was given a pair of soccer cleats at the beginning of the study and was not required to wear them but was highly encouraged to do so. All subjects wore cleats for all agility sessions after week 1.

Traditional Training. Traditional training consisted primarily of running on Mondays and Fridays, with calisthenics on Wednesday. Monday and Fridays' runs would start with a warm-up (one lap around track, jumping jacks, lunges, and bear crawl), followed by a self-paced two-mile run. Wednesday calisthenics were completed two times and consisted of overhead hand clap, eight-count body builders, mountain climbers, lunges, squat-reach jump, v-up sit-ups, burpees, trunk twisters, and side twists, along with a few linear sprints. Each day ended with a cool down period of walking and a few minutes of stretching.

The traditional group received a new pair of running shoes at the beginning of the study but was not required to wear them for the study.

Statistical Analyses

The dependent variable used in all analyses was a change (actual or percent) from pre to post training. Initially, an analysis of variance (ANOVA) was performed using group (agility, traditional) and gender (male, female) as factors. No dependent variable had a significant group/gender interaction. Since gender did not interact with group and there was a sample size issue with more males than females (14 M, 9 F in agility; 13 M, 5 F in traditional) it was decided to drop gender as a factor. A one-way ANOVA was then performed for all dependent variables.

In this model, a significant effect of group indicates the change from pre to post was different between the groups. Regardless of whether there was a significant effect of group, a two-tailed t-test was performed for each group separately to test Ho: mean change = 0 vs. Ha: mean change ≠ 0.

RESULTS

Of the 51 original enrollees, 41 completed the entire protocol. Body weight increased significantly for subjects in the traditional group from pre (72.0 kg) to post (73.2 kg) There was no change in the mean body weight of subjects in the agility group (68.7 kg) from pre to post testing. The difference in bodyweight change between groups was significant ($p<0.05$.) Additionally, both groups increased their percentages of body fat from pre to post testing as displayed in Figure 1. (For all figures, the presence of an asterisk indicates statistical significance.) The agility group went from 21.4% to 22.7% while the traditional group went from 22.8% to 24.6%. Although the traditional group gained slightly more fat (1.6 kg) than the agility group (0.9 kg), the difference between groups was not significant.

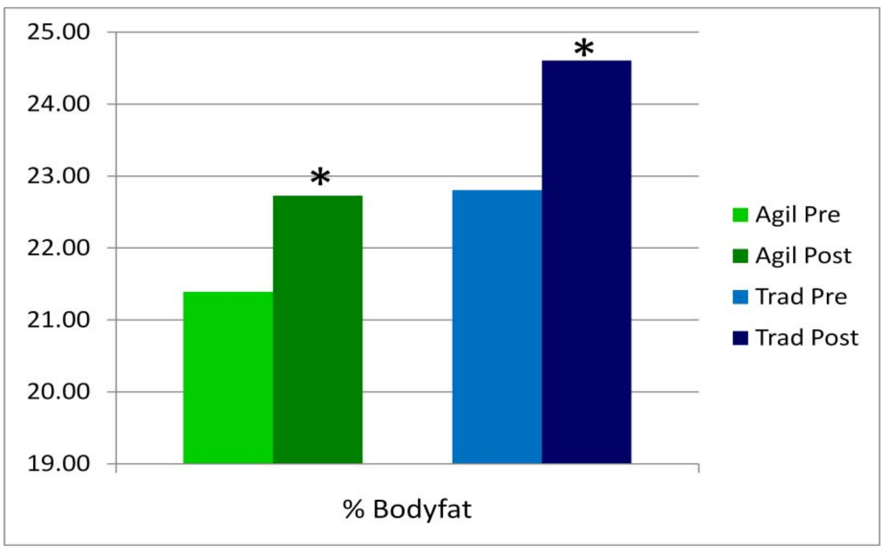

Figure 1. Body composition results.

Maximal oxygen capacity increased by 6.1% or 2.6 ml/kg/min ($p<0.05$) in the agility group and by a non-significant 1.7 % (0.9 ml/kg/min) for the traditional group. Although it was not significant, an ANOVA comparing the pre-to-post delta for VO_2max trended towards significance ($p=0.12$). The traditional group demonstrated a 6.6% ($p<0.05$) improvement in time-to-exhaustion (TTE) during the treadmill test whereas the agility group trended slightly downwards.

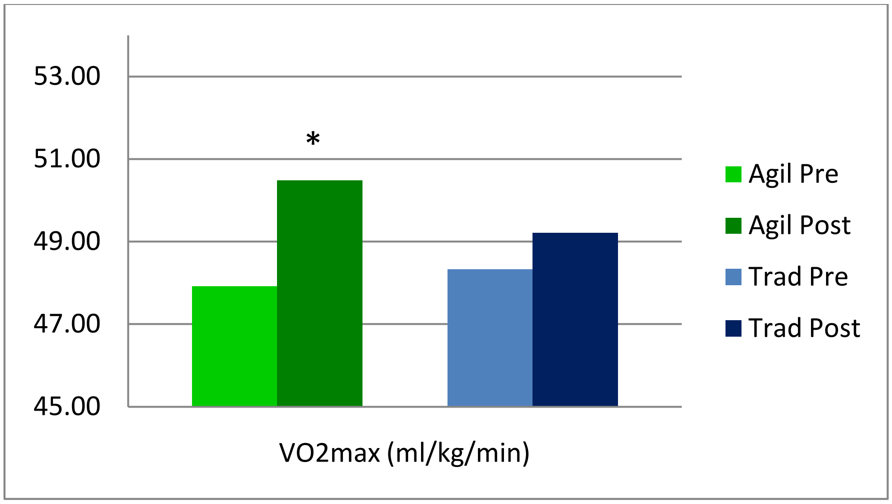

Figure 2. VO2max results.

Ventilatory Threshold (VT), as measured by time, significantly increased for both groups from pre to post testing but VT as a percent of VO_2max increased significantly only for the agility group (from 76% to 83%, $p < 0.05$.) The traditional group increased this measure by a non-significant margin (76% to 79%.) However, the pre-to-post delta between groups was not significant.

Both groups improved significantly from pre to post testing in the percentage of Makoto targets hit. Surprisingly, the traditional group's improvement was slightly larger than that of the agility group but the pre-to-post delta between groups was not significant. The traditional group also improved significantly on the speed to hit targets (figure 3.)

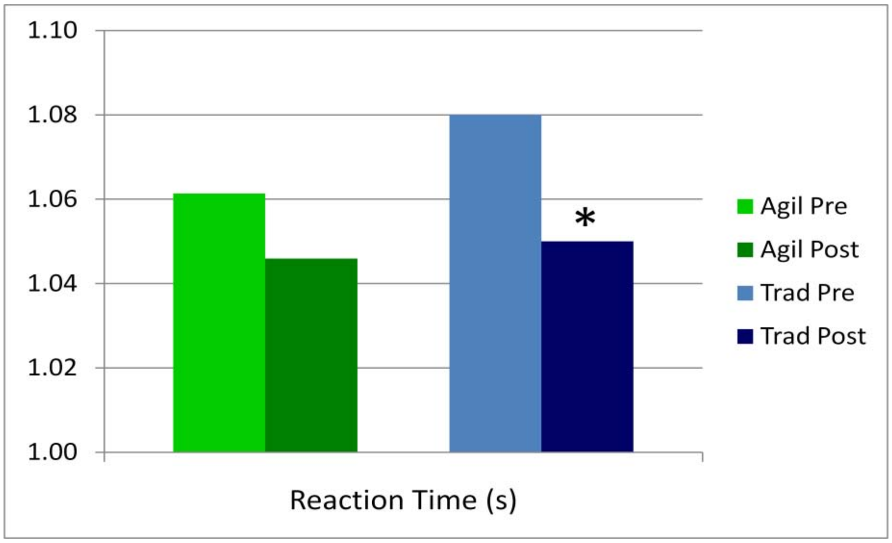

Figure 3. Makoto reaction time results.

The agility group slightly improved their vertical jump from pre to post testing, whereas the traditional group's mean vertical jump decreased slightly (figure 4). Neither of these changes were statistically significant. However, a strong trend towards significance was noted for the pre-to-post delta between groups ($p = 0.06$.) The Illinois Agility Test (IAT) produced similar results (figure 5) as the agility group improved their time from pre to post testing by a significant 0.86 s, or 3.8%, while the traditional group remained flat. The difference pre-to-post delta between groups was not significant but trended strongly towards the agility group improving more that the traditional ($p = 0.07$.)

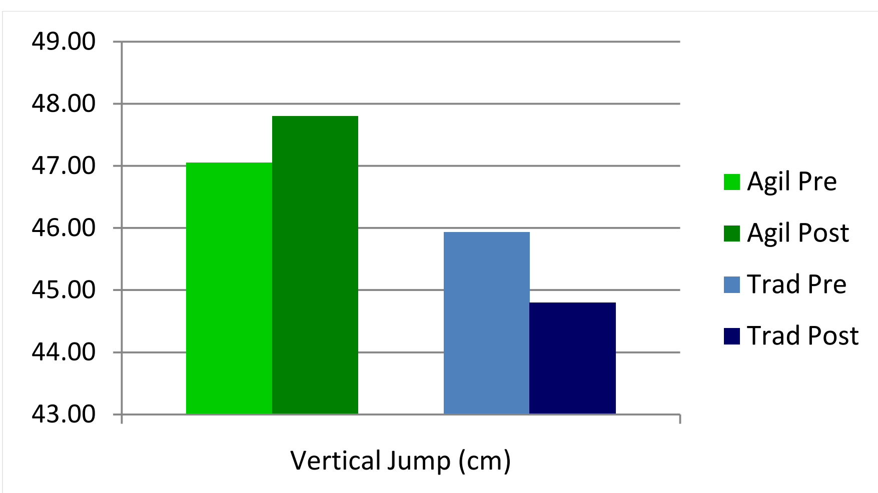

Figure 4. Vertical jump results.

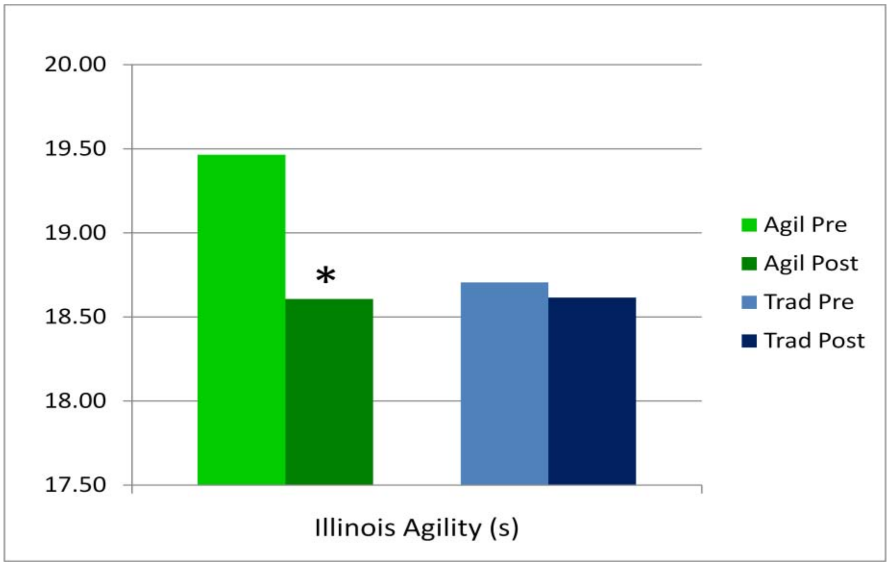

Figure 5. Illinois Agility Test results.

There were no significant differences in cortisol response to exercise from pre to post testing for either group nor were any pre-to-post delta differences between groups.

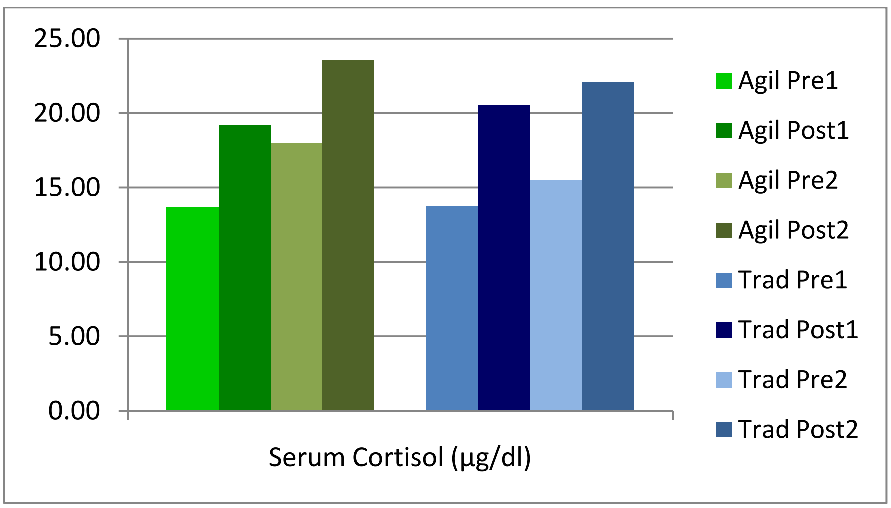

Figure 6. Cortisol results.

Cognitive Results:

The agility group improved by 8.8% on the continuous memory task ($p<0.05$) whereas the traditional group did not show improvement (figure 7). An ANOVA comparing the pre-to-post delta in continuous memory percent correct responses trended towards significance ($p = 0.07$). Visual vigilance increased significantly with agility training but not with traditional training however the pre-to-post delta between groups was not different (figure 8).

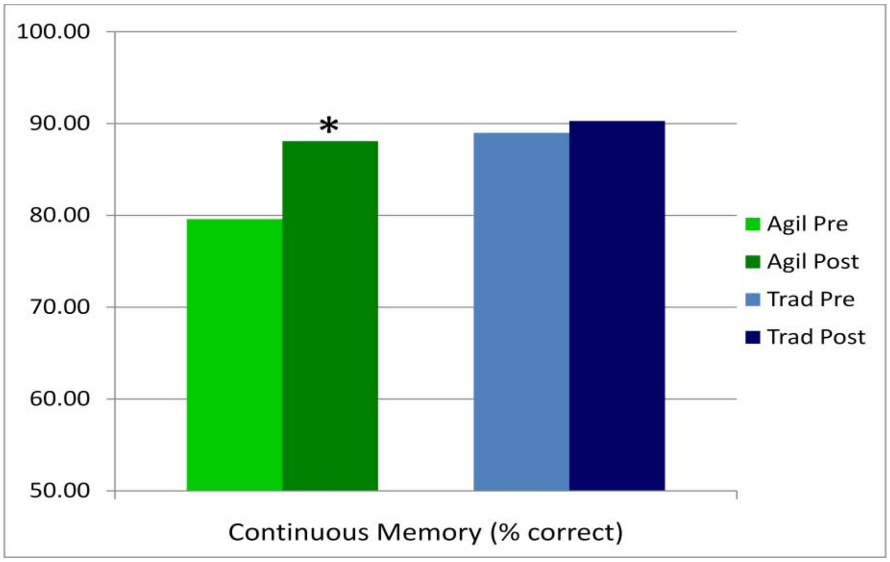

Figure 7. Continuous memory test results.

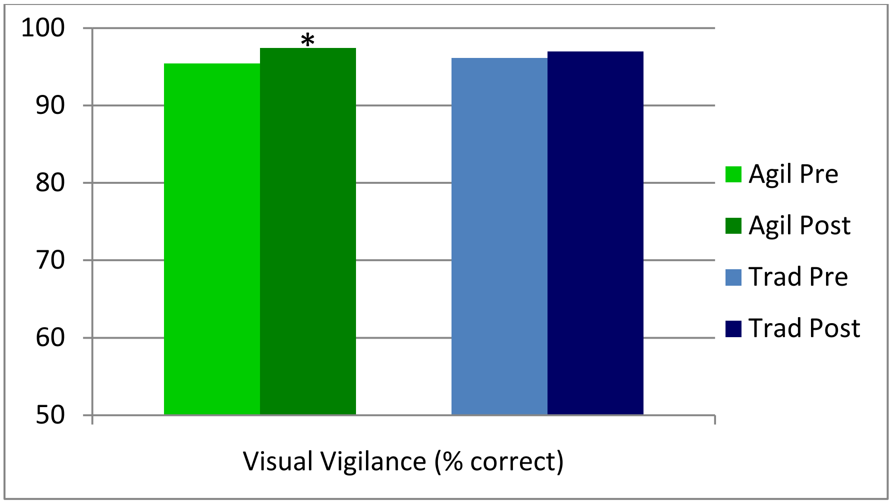

Figure 8. Visual vigilance test results.

Our first measure for selective attention was the percentage of correct responses on the dichotic listening test. There were no significant within-group changes in percent correct responses, although there was a mild trend in the traditional training group toward decreased performance at the post-training session (figure 9). However, there was a significant between-group effect of training revealed by an AVOVA of the deltas for response time for correct responses ($p<0.05$);

the agility group showed slightly faster responses during post testing than in pre testing whereas the traditional group was significantly slower during their post test (figure 10).

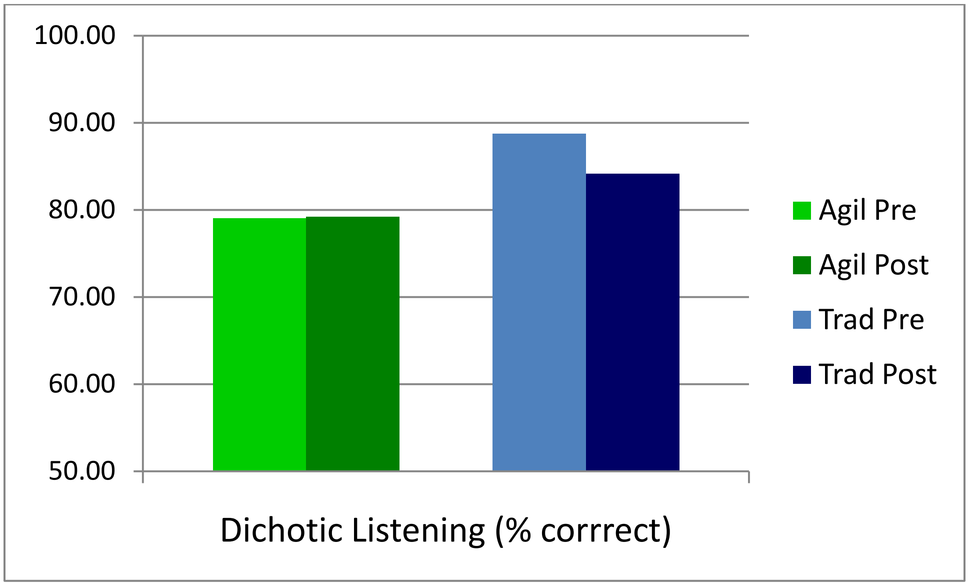

Figure 9. Dichotic listening correct response results.

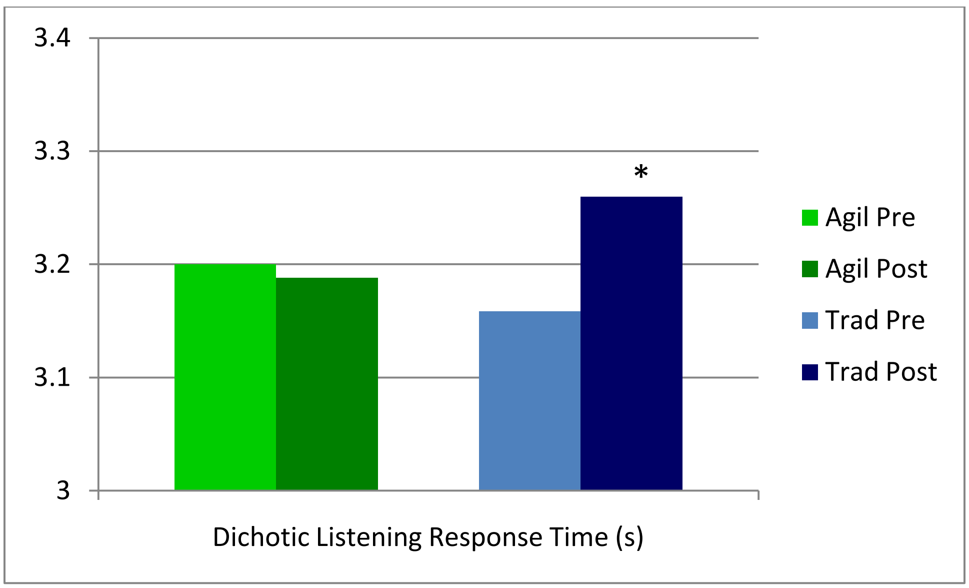

Figure 10. Dichotic listening response time results.

Figures 2 – 6 and figure 10 demonstrate actual changes for each variable measured. Absolute changes may be important for interpretation and for real world application. Figure 11 is provided as a graphic summary of percent changes of all variables. It is important to note that it was these changes on which our statistical analyses were based.

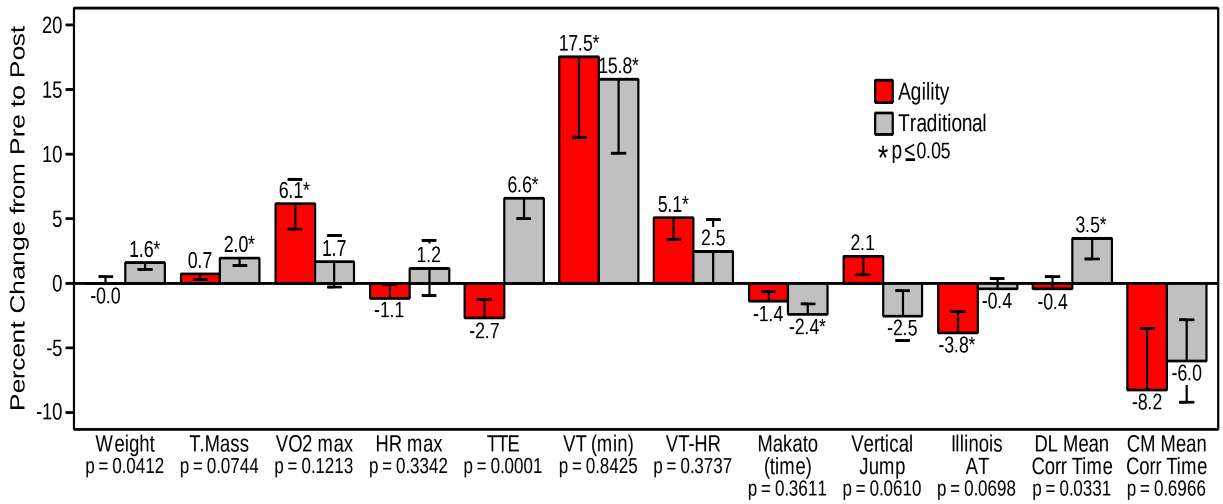

Figure 11. Percent changes for selected variables.

DISCUSSION

The primary findings of this investigation are that 6 weeks of agility training resulted in significant improvements in cardio-respiratory capacity, physical agility, and working memory in moderately trained men and women, while 6 weeks of traditional physical training did not significantly improve performance in those areas. Further, agility training appears to have resulted in greater improvements in selective attention responsiveness than did traditional training.

The agility group significantly improved their maximal oxygen carrying capacity during the training period while the traditional group did not. Because the VO_2max test was a treadmill test it seemed probable that, due to specificity of training, the traditional group might improve on it to a greater degree than the agility group. However, that was not the case. We suspected the lack of improvement in VO_2max for the traditional group may have simply been due to their greater weight gain but a review of absolute VO_2maxes for each group reveals that the traditional group increased by 0.13 L/min while the agility group increased by 0.21 L/min. This data supports that of Sporis et al. (2008) who observed a significant improvement in VO_2max with 6 weeks of agility training and a lack of improvement in VO_2max in a linear running group. Sporis et al. also demonstrated that the agility group improved running performance over short (200m) to moderate (2400m) distances whereas the running group did not. This indicates that for general cardio-respiratory fitness, agility training is as effective or more effective than linear running while potentially providing other physiological and cognitive benefits that linear running does not provide. The significant increase in TTE for the traditional group is likely explained by better running economy. Although neither change in running economy was significant (nor were the changes different from each other) the traditional group had a slight improvement whereas the agility group demonstrated a slight decrease.

Although both groups' percentage of body fat increased, the agility group appeared to fare slightly better than the traditional group with regards to body composition changes over the 6-week training period. It may initially seem surprising that both exercise groups gained body fat, but that is readily explained by their condition at the start of the protocol. Prior to arriving at technical school, subjects had immediately graduated from basic military training (BMT) where meal times are regulated and trainees are not allowed to eat or drink except at meal times. Trainees are allowed to eat ad lib during technical school and likely increased their calorie intake from BMT. Furthermore, they are not allowed sodas, snacks, or alcohol in BMT whereas they are allowed those items during technical school. It is likely that the quality of calories they consumed also worsened. Last, although programmed physical training sessions are not appreciably different, general physical activity is greater at BMT than in technical training. Although both groups' body composition grew worse over the training period, the trend was for the agility group to better attenuate the fat gain. We did not measure exact calorie expenditure or intake during the protocol but we did strictly equilibrate duration, frequency, and intensity of exercise between groups so the agility group must have consumed fewer calories or expended more calories after training than did the traditional group. The latter could have been due to more general activity or to greater excess post-exercise oxygen consumption (EPOC). The magnitude of EPOC after exercise generally depends on both the duration and intensity of exercise. However, differences in exercise mode may contribute to the discrepant findings of EPOC magnitude and duration (Borsheim and Bahr, 2003.) Future studies comparing agility training to linear running may wish to further explore this possibility.

In addition to the agility group showing significant improvement in the Illinois Agility Test (IAT), we observed strong group by time interaction trends in both vertical jump ($p=0.06$) and IAT ($p=0.07$) performance. Whereas the traditional group did no jumping or change of direction drills during training, the agility group did a great deal of change of direction drills and a few drills involved jumping. Such training has been demonstrated to improve performance of vertical jump and various agility tests (Polman et al., 2009; Galpin et al., 2008; Young et al., 2001). As such, significant differences within the agility group were expected and were indeed observed. Differences in the changes between groups were also expected in these variables but were not observed, although strong trends were observed. With slightly more power we likely would have seen such differences. The agility group's 3.8% improvement on the IAT compares favorably to that measured in a recent six-week study of plyometric training (Miller et al., 2006) which utilized a similar volume of training and observed a 2.9% improvement.

The agility group did not fare better on the Makoto reaction time test than the traditional group. The Makoto test was an attempt to test “reactive” agility: rapid whole body movement with change of velocity or direction in response to a stimulus, such as occurs in sports (avoiding a defender, intercepting the path of a ball, etc.) and on the battlefield (seeking cover, clearing a building, etc.) A strong and rational case for including this type of decision-making as a component of agility has been advanced in recent publications (Sheppard et al., 2006; Young et al., 2006). Two such tests have been developed (Farrow et al, 2005; Sheppard et al., 2006) and validated as accurate measures of unplanned or “reactive” agility. However, both are very sport specific (and claim that specificity is very important) and have not yet gained wide use. The Makoto arena certainly demands a reaction in response to a stimulus. However, it is not sport or task specific. We suspect that there is a greater learning curve and higher technique requirements than we originally predicted and that with only one 30-s practice session, our subjects may not have been trained to asymptote prior to being tested. Future investigations of agility training should consider developing, validating, and incorporating reactive agility tests specific to their population.

We did not observe any significant differences between groups or between tests in cortisol baseline levels or cortisol response to exercise stress. Both groups displayed baseline cortisol levels within normal limits pre and post-training. Both groups displayed a slight, non-significant blunting of their cortisol response to exercise after the 6 weeks of training. This is unsurprising as chronic endurance training has been demonstrated to attenuate the HPA response to exercise stress (Watanabe et al., 1991). It is quite possible that there were changes between groups in cortisol response that we did not detect. Different modes of exercise have different affects on cortisol, both chronically (Watanabe et al., 1991; Kraemer and Ratamess, 2005) and acutely (Filaire et al, 1996) although the influence of AT on human cortisol response has not been examined. There may be two prime reasons that we failed to detect a difference. First, cortisol response to exercise is highly dependent on blood glucose levels and therefore on pre-exercise nutrition (Bird et al., 2006). Although we controlled for circadian variation we did not control for pre-exercise nutrition. Second, we observed two cortisol snapshots: one upon arrival to our lab and the other following exercise. However cortisol response to exercise may be better observed with multiple samples over a few hours following exercise. Future protocols should consider controlling for pre-test nutrition and taking saliva samples for cortisol every 15 minutes from baseline until three hours after stress.

Notably, no study-related injuries occurred in either group. Anecdotally, it seems fears of being injured during agility training are often greater than for linear running. With zero agility training injuries, the current study refuted such anecdotal evidence. Recent investigations have indicated that agility training may actually reduce training related injuries when compared to traditional training (Knapik et al., 2003; Bullock et al., 2010) and that agility training may reduce the chance of injury during real world (sport or occupational) activity (Mercer and Strock, 2004;

Besier et al., 2001). Work from our lab with combat controller trainees supported that premise as well (Walker et al., 2010). After substituting agility training for nearly half of the previously performed linear running we observed a 67% decrease in overuse injuries with a concurrent increase in several physiological performance variables.

Also noteworthy was the apparent preference of the subjects to perform agility training over traditional training. Four subjects who were randomly placed in the traditional group dropped out of the protocol within the first week of training, and claimed they did so due to disappointment over their grouping. None of the agility subjects withdrew from the study for that reason. Finally, several of the agility group subjects requested the agility training continue after the conclusion of the study, as opposed to their returning to traditional training. Previous research has indicated that intrinsic motivation, such as enjoyment and challenge, may facilitate improved adherence to exercise regimens (Fredrick et al., 2003). This may be another reason to incorporate agility training into physical training programs.

The agility training group showed a significant 9% improvement in continuous memory performance over the 6 week period of this study, while the traditional training group showed no improvement. The size of these effects, obtained in adults through only a six week intervention, suggests very strongly that agility training should be considered in future studies looking for exercise interventions to enhance cognitive performance. Likewise, the agility group demonstrated a significant 1.9% improvement in visual vigilance over the six week study, while the traditional training group did not show improvement. It should be noted that this effect is found contrasting agility training against the type of intense aerobic exercise condition that is more often used to find cognitive benefits from exercise.

The significant effect of treatment in dichotic listening response time is interesting, but difficult to interpret, given that it is mostly due to a decline of performance in the traditionally trained group, rather than an improvement of performance in the agility trained group. This may indicate that there was some factor in the students' environment during the six week period that tended to impact performance on selective attention as measured by dichotic listening, the negative effect of which was ameliorated by agility training. It is interesting to compare this result to the fact that during the six week period, the traditional group gained more weight and body fat than did the agility group, suggesting an ameliorating effect of agility training in that physical regard as well. The environment during this six week testing period was significantly more liberal than that of BMT, immediately prior to students beginning this study, with multiple distractions available that were denied during BMT. Selective attention is sensitive to a number of environmental factors (for example sleep deprivation, Chee et al., 2010). There is much interest in the potential for exercise to ameliorate negative effects on selective attention from causes such as multi-tasking or mild cognitive impairment (Baker et al., 2010), with the focus being on contrasting aerobic exercise (in the case of Baker et al., subjects exercised on a treadmill, stationary bike or elliptical machine) against stretching. The agility training used in the present study is a third alternative, both high intensity and demanding of integrative, coordinated motor control and cognitive processes in a way that many exercise modalities are not. The present data may suggest that agility training offers a more effective intervention against cognitive impact of technological distraction, such as the students encountered anew during the study period, than did the aerobically intensive condition.

Kramer et al (1999) presented evidence that improvements in fitness should be reflected in enhanced performance on executive control processes such as working memory, coordination, inhibition, scheduling and planning. These data are consistent with that result, but further suggestive that agility training in particular may provide an additional key to unlocking the secrets of cognitive enhancement through exercise.

CONCLUSIONS

Based on the results of this investigation, it appears that three sessions of agility training provide greater benefit to physical and cognitive performance. Air Force personnel, particularly Battlefield Airmen, should incorporate agility training into their physical training programs. Future research in this area may wish to explore how agility training influences the performance of real world athletic and/or occupational events.

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List of Symbols, Abbreviations, and Acronyms

711 HPW – 711 Human Performance Wing
AFRL – Air Force Research Laboratory
ACSM - American College of Sports Medicine
ACTH - Adrenocorticotropic Hormone
ANOVA – Analysis of Variance
AT – Agility Training
BMT – Basic Military Training
bpm – Beats per Minute
CCT - Combat Controller
Cm – centimeters
DEXA – Dual Energy X-ray Analysis
EE – Environmental Enrichment
EPOC – post-exercise oxygen consumption
et al. – "and others" (Latin)
GE – General Electric
HPA – Hypothalamic-Pituitary-Adrenal
HR – Heart Rate
IAT – Illinois Agility Test
kg – kilograms
$L \cdot min^{-1}$ - Liters per minute
m – meters
microL – microliters
ml – milliliters
$mL \cdot kg^{-1} \cdot min^{-1}$ – milliliters per kilogram per minute
$mmol \cdot L^{-1}$ – millimoles per liter
mph – miles per hour
n – number of subjects
NTI ATS – NTI Armory Test System
PT – Physical Training
s or secs – seconds
SD - Standard Deviation
STTS - Special Tactics Training Squadron
TTE – time-to-exhaustion
U.S. – United States
USAF – United States Air Force
USAFSAM - United States Air Force School of Aerospace Medicine
VO_2max - Maximal Oxygen Uptake

VT – Ventilatory Threshold